US009046599B2

(12) **United States Patent**
Morikawa et al.

(10) **Patent No.: US 9,046,599 B2**
(45) **Date of Patent: Jun. 2, 2015**

(54) **OBJECT DETECTION APPARATUS AND METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 53 days.

(21) Appl. No.: **13/945,212**

(22) Filed: **Jul. 18, 2013**

(65) **Prior Publication Data**

US 2014/0062759 A1 Mar. 6, 2014

(30) **Foreign Application Priority Data**

Sep. 6, 2012 (JP) 2012-196688

(51) **Int. Cl.**

G01S 13/06	(2006.01)
G01S 17/42	(2006.01)
G01S 17/87	(2006.01)
G01S 17/93	(2006.01)
G01S 7/481	(2006.01)

(52) **U.S. Cl.**

CPC ***G01S 13/06*** (2013.01); ***G01S 17/42*** (2013.01); ***G01S 17/87*** (2013.01); ***G01S 17/936*** (2013.01); ***G01S 7/4817*** (2013.01)

(58) **Field of Classification Search**

USPC 356/3.01–3.15, 4.01–4.1, 5.01–5.15, 356/6–22, 28, 28.5

See application file for complete search history.

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(57) **ABSTRACT**

An object detection apparatus includes: a first radar configured to measure first positional information regarding a first object existing in a first scan range; a second radar configured to measure second positional information regarding a second object existing in a second scan range on the basis of second reflected wave of second wave radiated onto the second scan range including the first region and a second region, the second wave being radiated in such a way as to scan the first region in a direction opposite a direction in which the first radar radiates the first wave; and a processor configured to detect a third object existing in the first region on the basis of the first positional information and the second positional information.

12 Claims, 14 Drawing Sheets

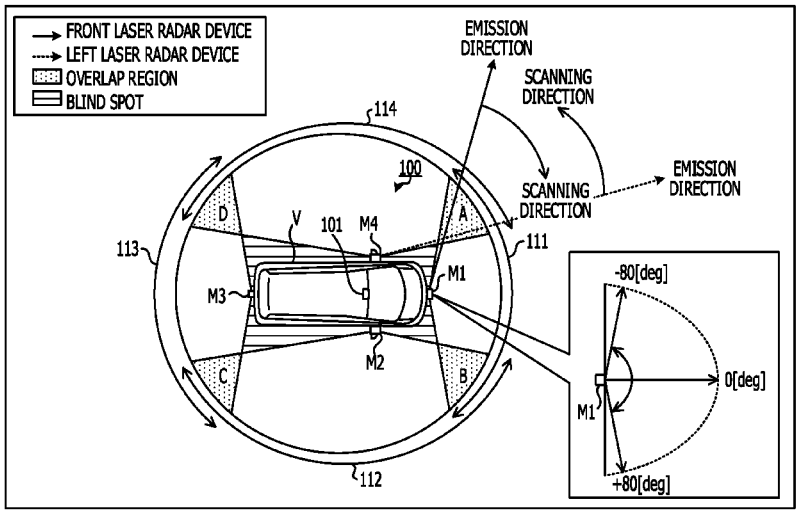


FIG. 1

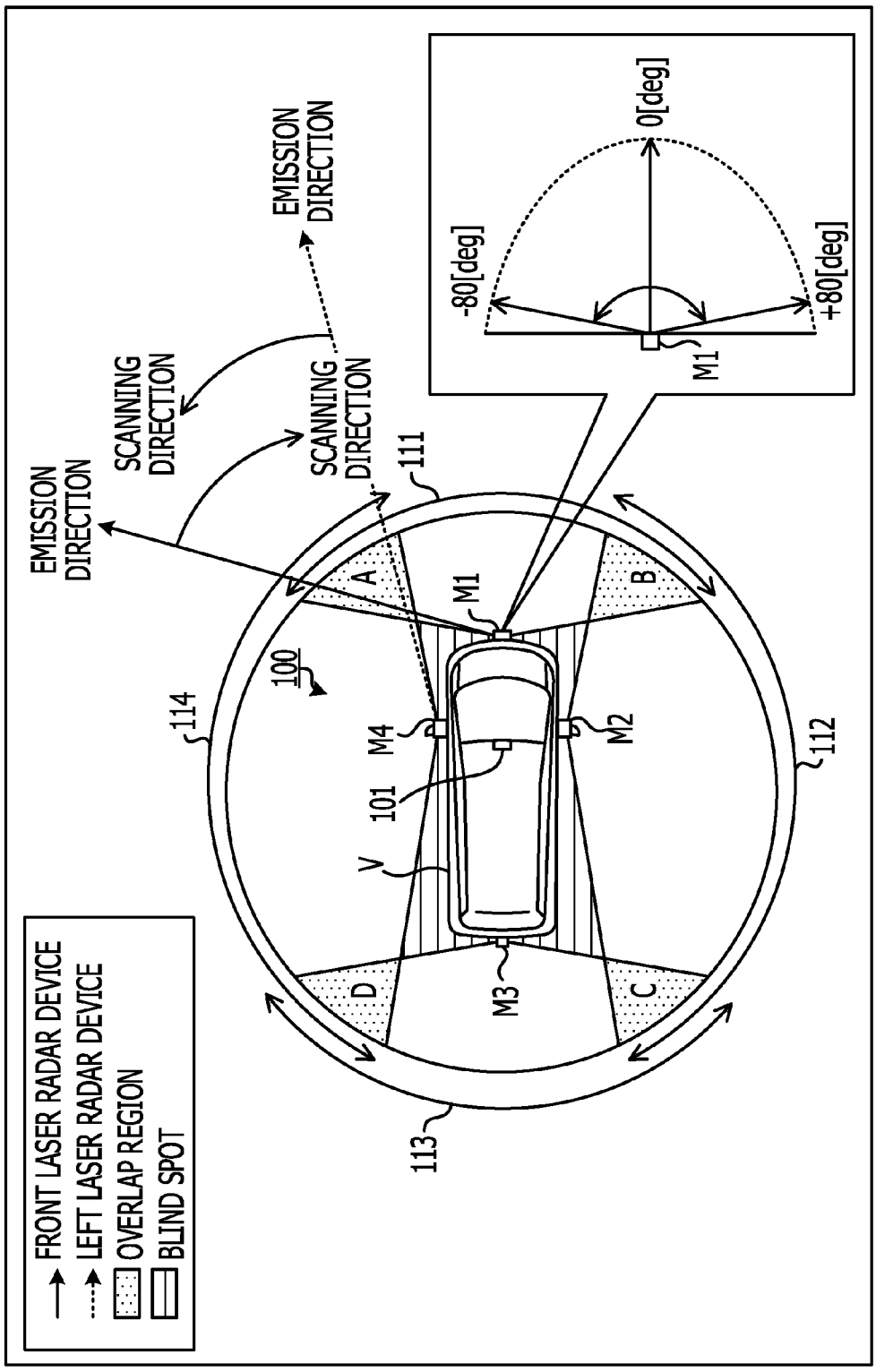

FRONT LASER RADAR DEVICE
LEFT LASER RADAR DEVICE
OVERLAP REGION
BLIND SPOT
EMISSION DIRECTION
SCANNING DIRECTION
EMISSION DIRECTION
SCANNING DIRECTION
0[deg]
-80[deg]
+80[deg]
M1
111
A
B
C
D
M1
M2
M3
M4
100
101
V
112
113
114

FIG. 2

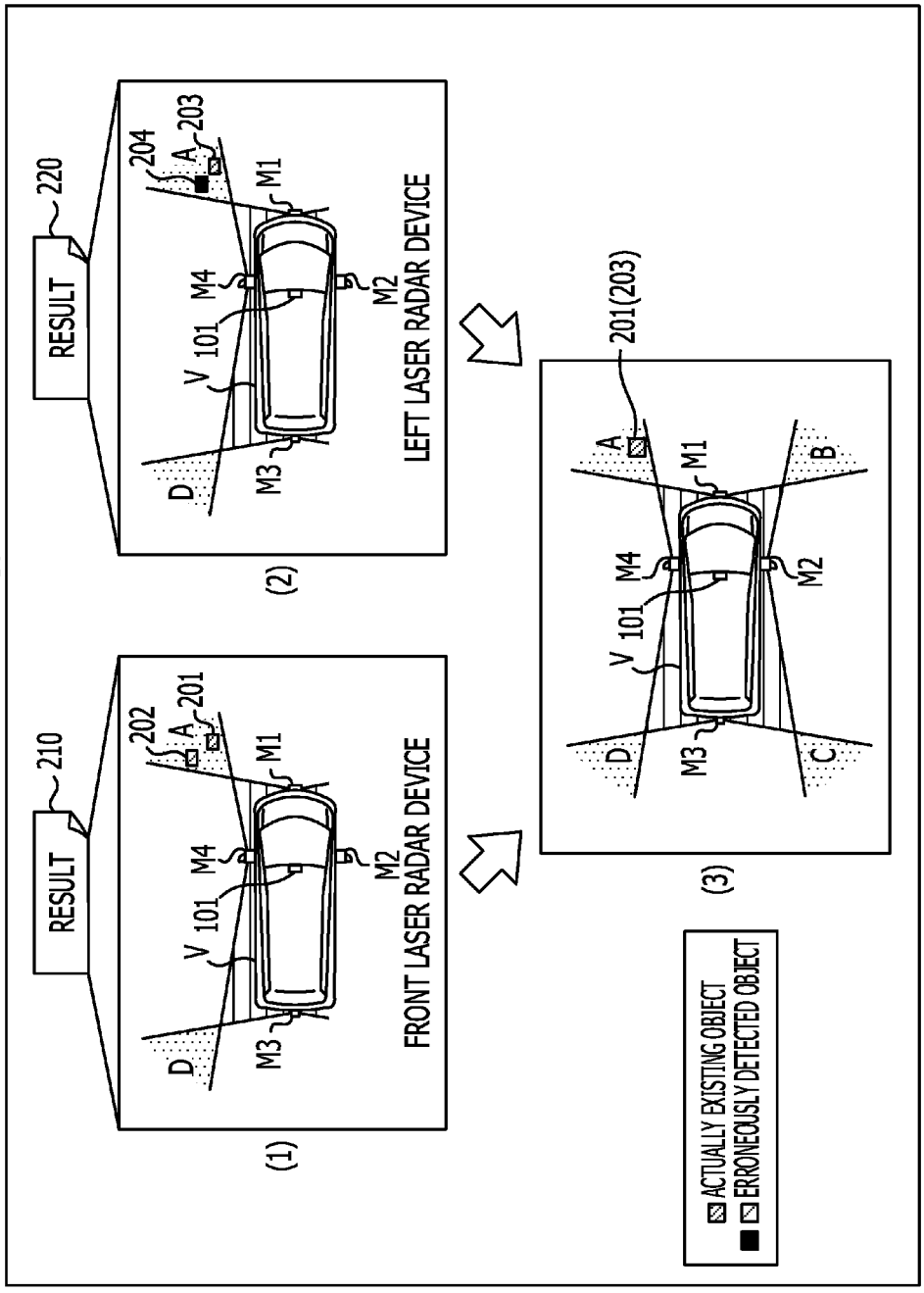

RESULT
210
202
A
201
M1
M4
V
101
M2
M3
D
FRONT LASER RADAR DEVICE
(1)
RESULT
220
204
A
203
M1
M4
V
101
M2
M3
D
LEFT LASER RADAR DEVICE
(2)
201(203)
A
M1
B
M4
M2
V
101
D
M3
C
(3)
ACTUALLY EXISTING OBJECT
ERRONEOUSLY DETECTED OBJECT

FIG. 3

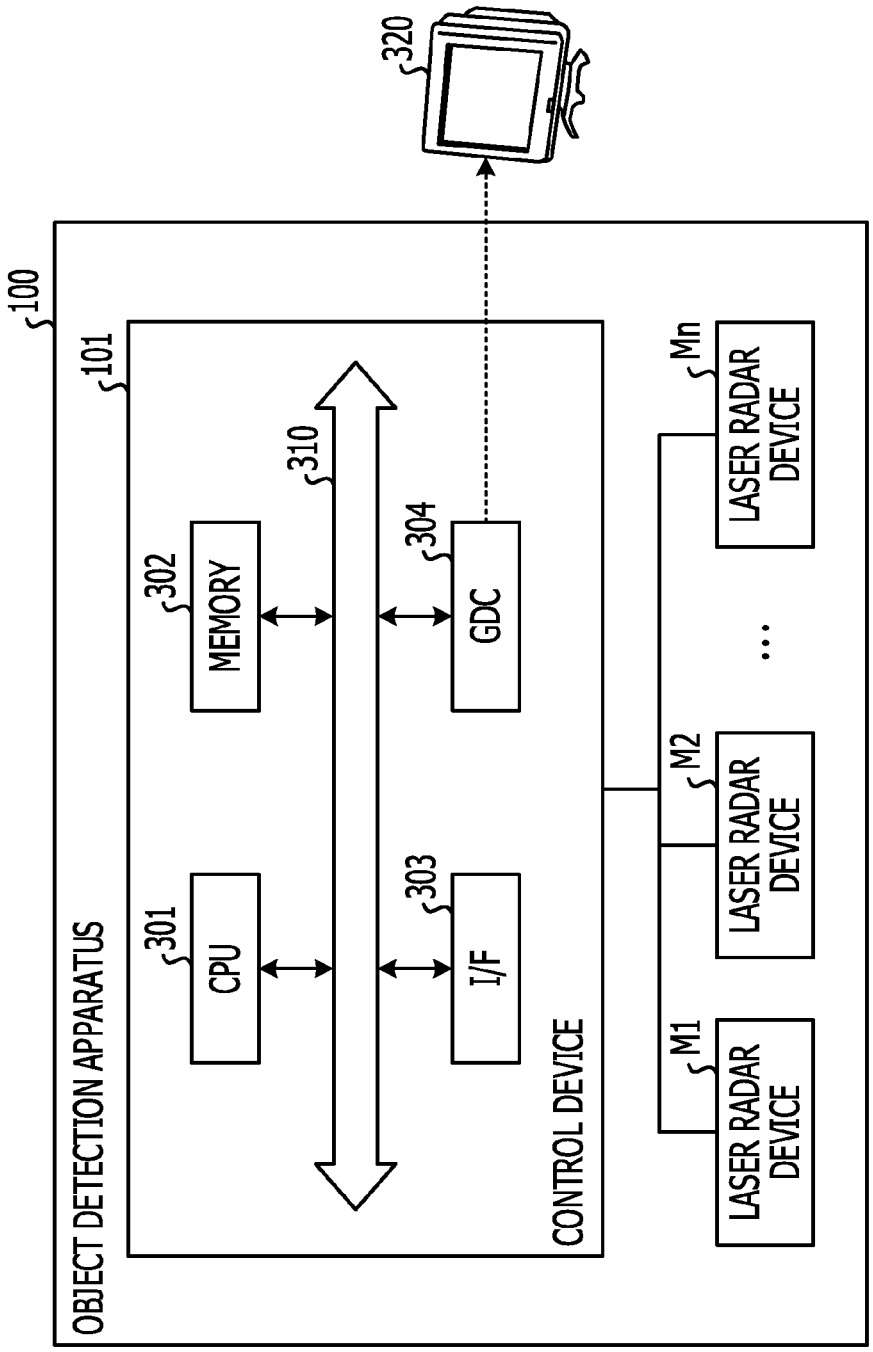

320
100
OBJECT DETECTION APPARATUS
101
CONTROL DEVICE
310
301
CPU
302
MEMORY
303
I/F
304
GDC
M1
LASER RADAR DEVICE
M2
LASER RADAR DEVICE
...
Mn
LASER RADAR DEVICE

FIG. 4

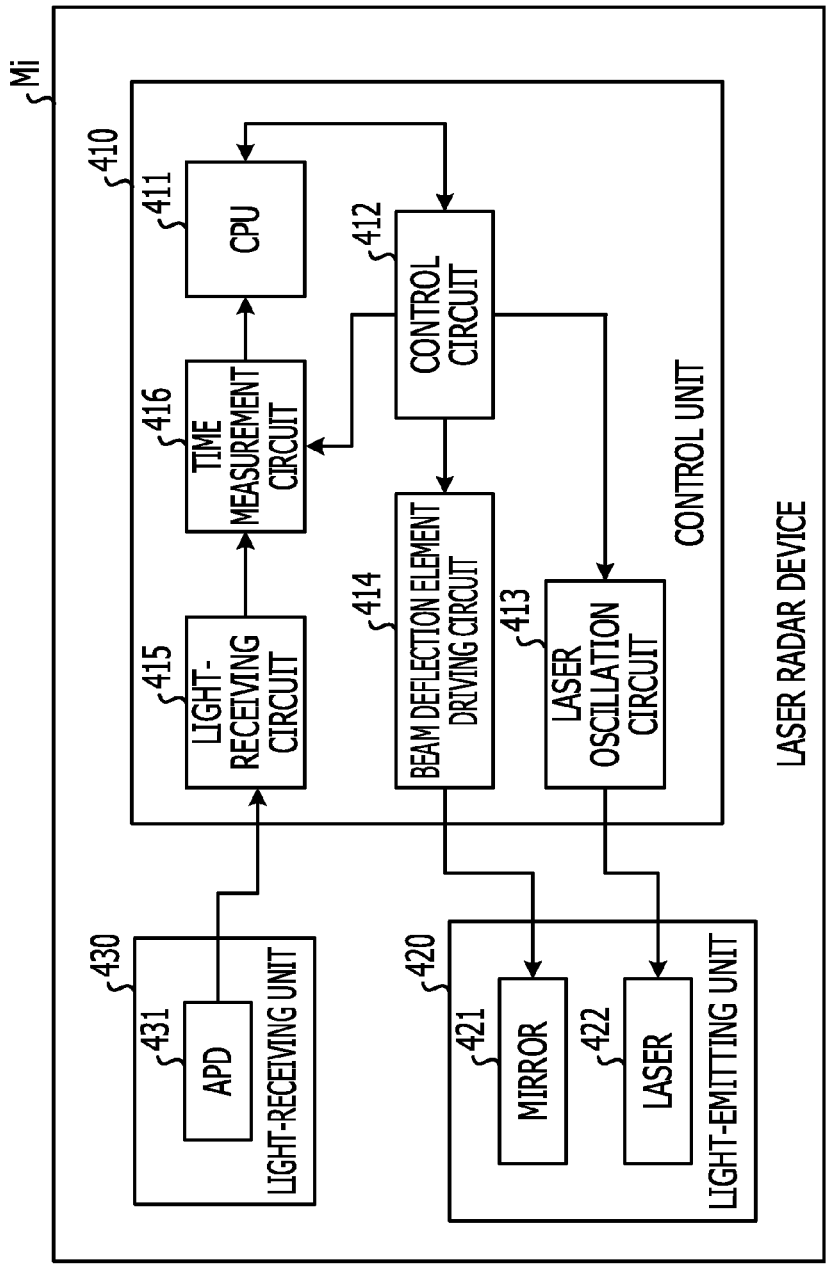

Mi
410
411
CPU
412
CONTROL CIRCUIT
416
TIME MEASUREMENT CIRCUIT
415
LIGHT-RECEIVING CIRCUIT
414
BEAM DEFLECTION ELEMENT DRIVING CIRCUIT
413
LASER OSCILLATION CIRCUIT
CONTROL UNIT
LASER RADAR DEVICE
430
431
APD
LIGHT-RECEIVING UNIT
420
421
MIRROR
422
LASER
LIGHT-EMITTING UNIT

FIG. 5

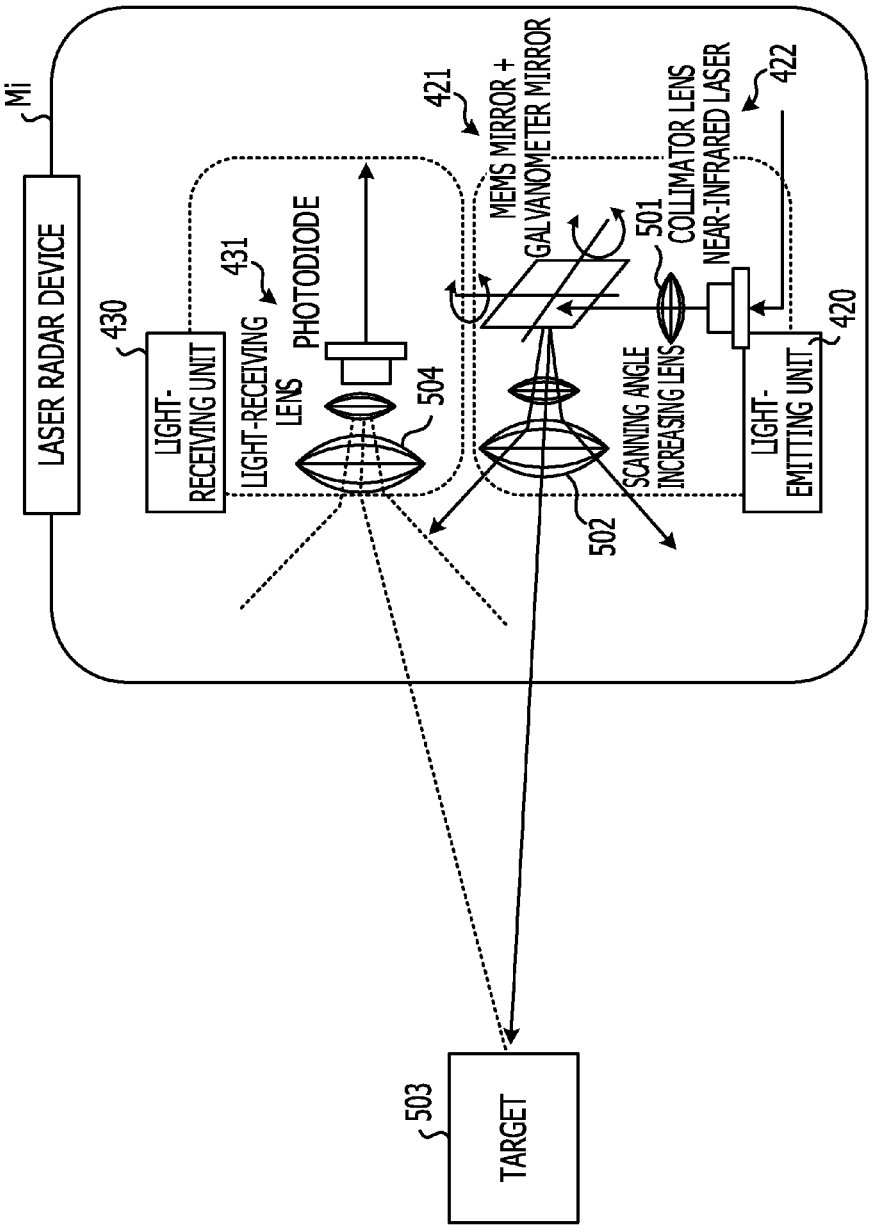

Mi
LASER RADAR DEVICE
LIGHT-RECEIVING UNIT
430
431
PHOTODIODE
LIGHT-RECEIVING LENS
504
421
MEMS MIRROR + GALVANOMETER MIRROR
501
COLLIMATOR LENS
422
NEAR-INFRARED LASER
420
LIGHT-EMITTING UNIT
SCANNING ANGLE INCREASING LENS
502
503
TARGET

FIG. 6

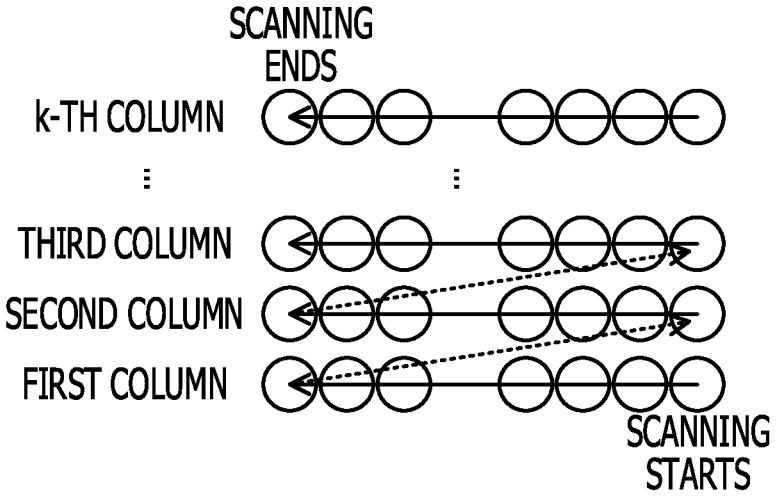

SCANNING
ENDS
k-TH COLUMN
THIRD COLUMN
SECOND COLUMN
FIRST COLUMN
SCANNING
STARTS

FIG. 7

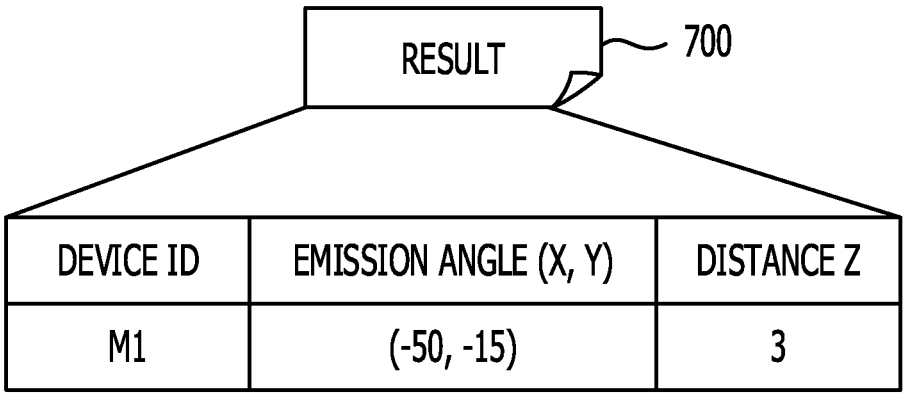


FIG. 8

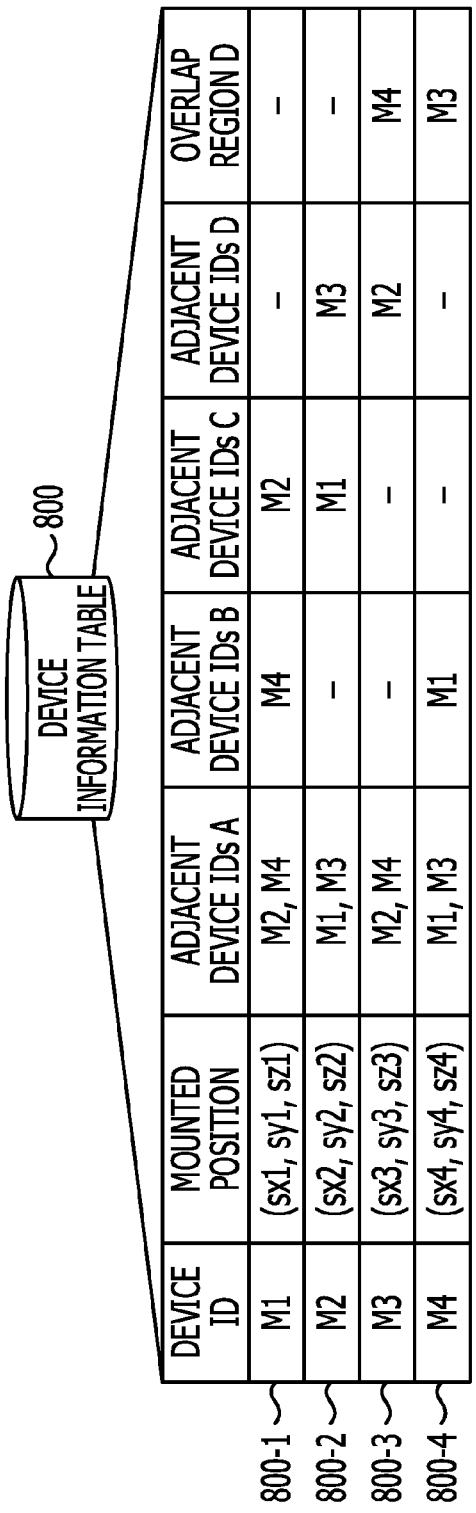
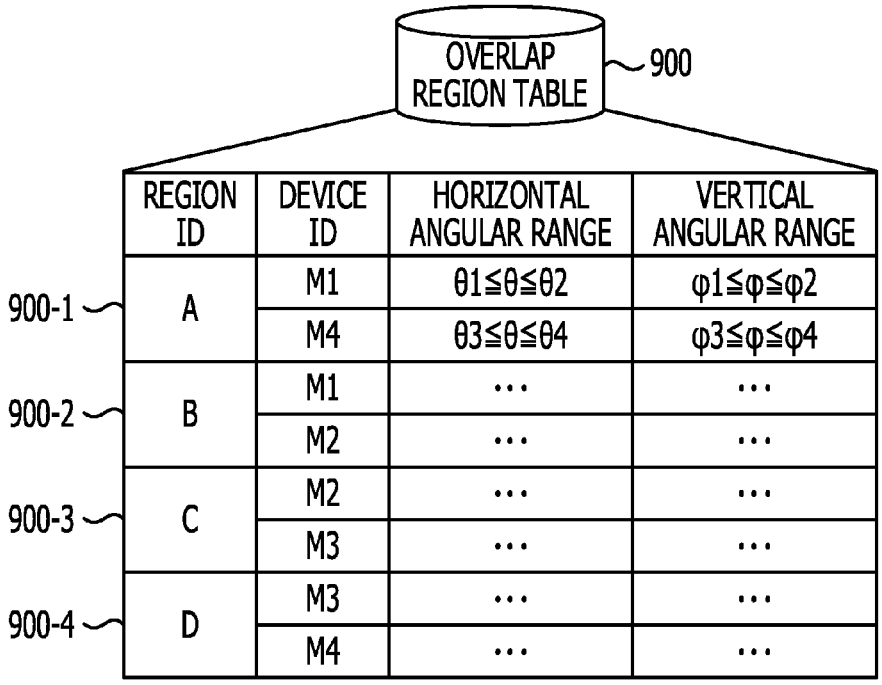

800
DEVICE INFORMATION TABLE
DEVICE ID
MOUNTED POSITION
ADJACENT DEVICE IDs A
ADJACENT DEVICE IDs B
ADJACENT DEVICE IDs C
ADJACENT DEVICE IDs D
OVERLAP REGION D
M1
(sx1, sy1, sz1)
M2, M4
M4
M2
–
–
M2
(sx2, sy2, sz2)
M1, M3
–
M1
M3
–
M3
(sx3, sy3, sz3)
M2, M4
–
–
M2
M4
M4
(sx4, sy4, sz4)
M1, M3
M1
–
–
M3
800-1
800-2
800-3
800-4

FIG. 9



REGION ID	DEVICE ID	HORIZONTAL ANGULAR RANGE	VERTICAL ANGULAR RANGE
A	M1	$\theta 1 \leqq \theta \leqq \theta 2$	$\varphi 1 \leqq \varphi \leqq \varphi 2$
	M4	$\theta 3 \leqq \theta \leqq \theta 4$	$\varphi 3 \leqq \varphi \leqq \varphi 4$
B	M1	...	...
	M2	...	...
C	M2	...	...
	M3	...	...
D	M3	...	...
	M4	...	...

FIG. 10

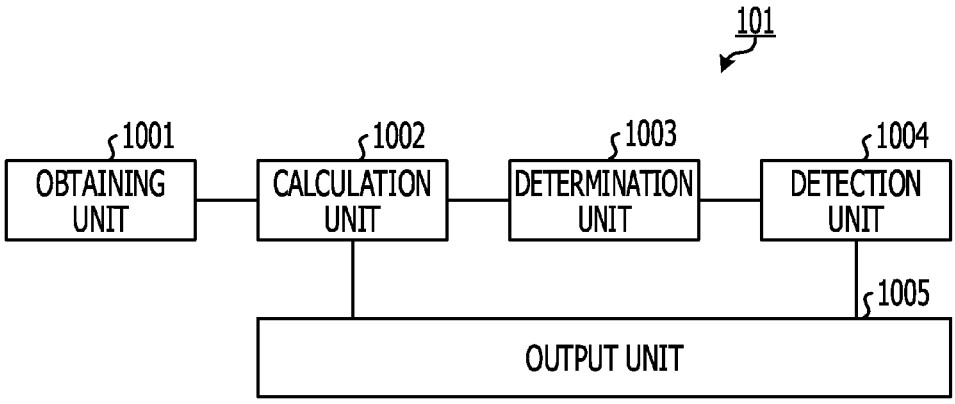

101
1001
OBTAINING UNIT
1002
CALCULATION UNIT
1003
DETERMINATION UNIT
1004
DETECTION UNIT
1005
OUTPUT UNIT

FIG. 11

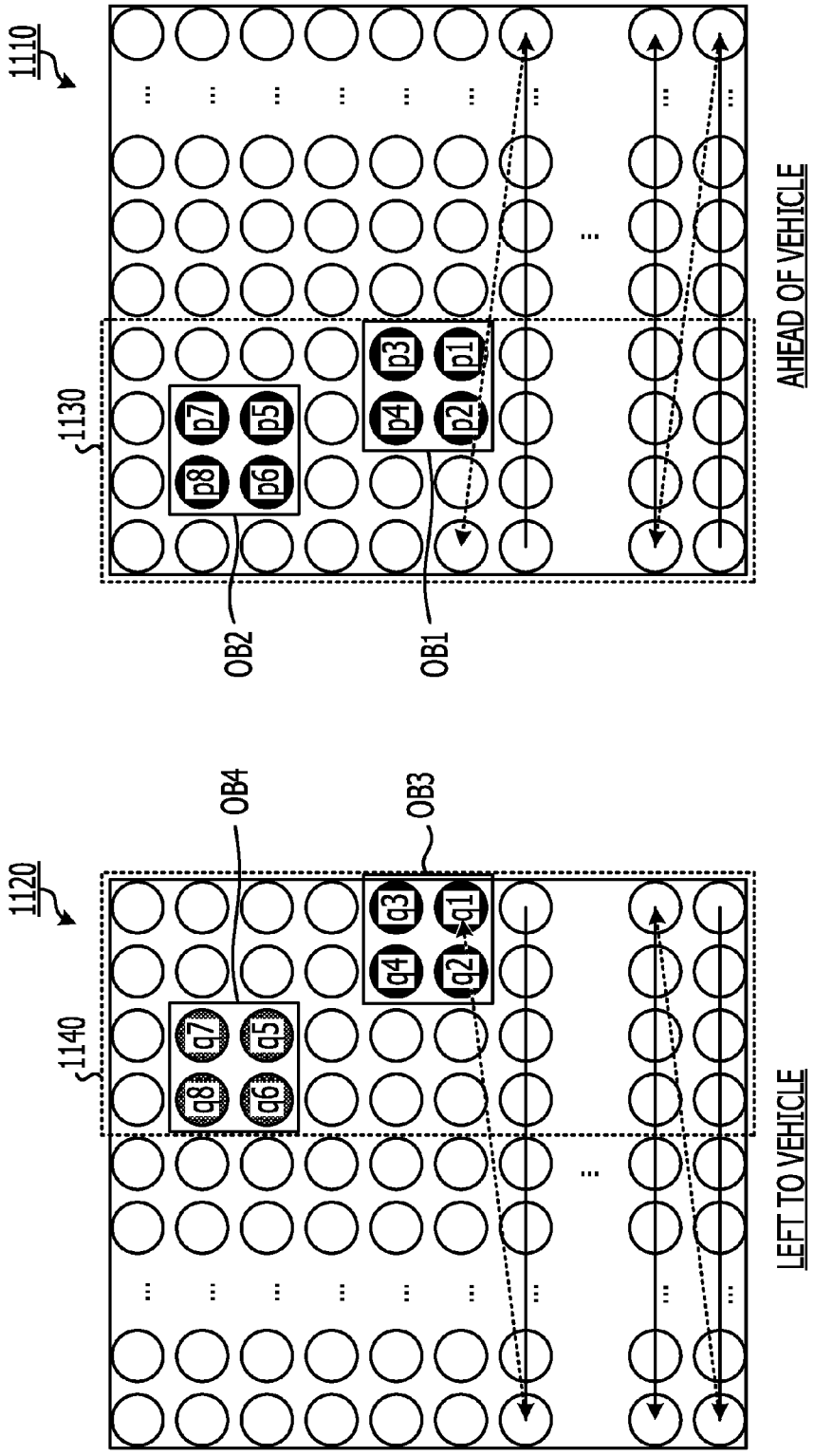

1110
1130
p1
p2
p3
p4
p5
p6
p7
p8
OB1
OB2
AHEAD OF VEHICLE
1120
1140
q1
q2
q3
q4
q5
q6
q7
q8
OB3
OB4
LEFT TO VEHICLE

FIG. 12

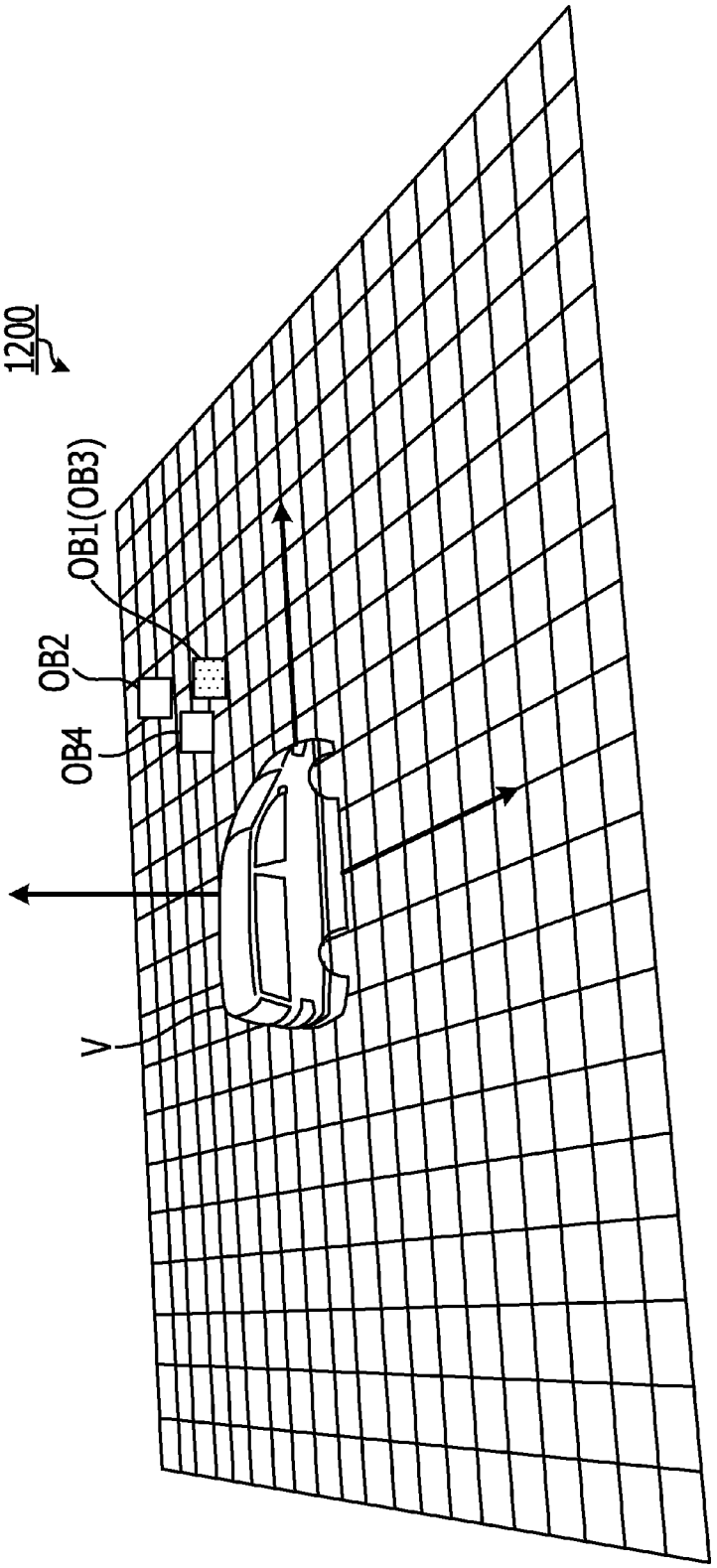


FIG. 13

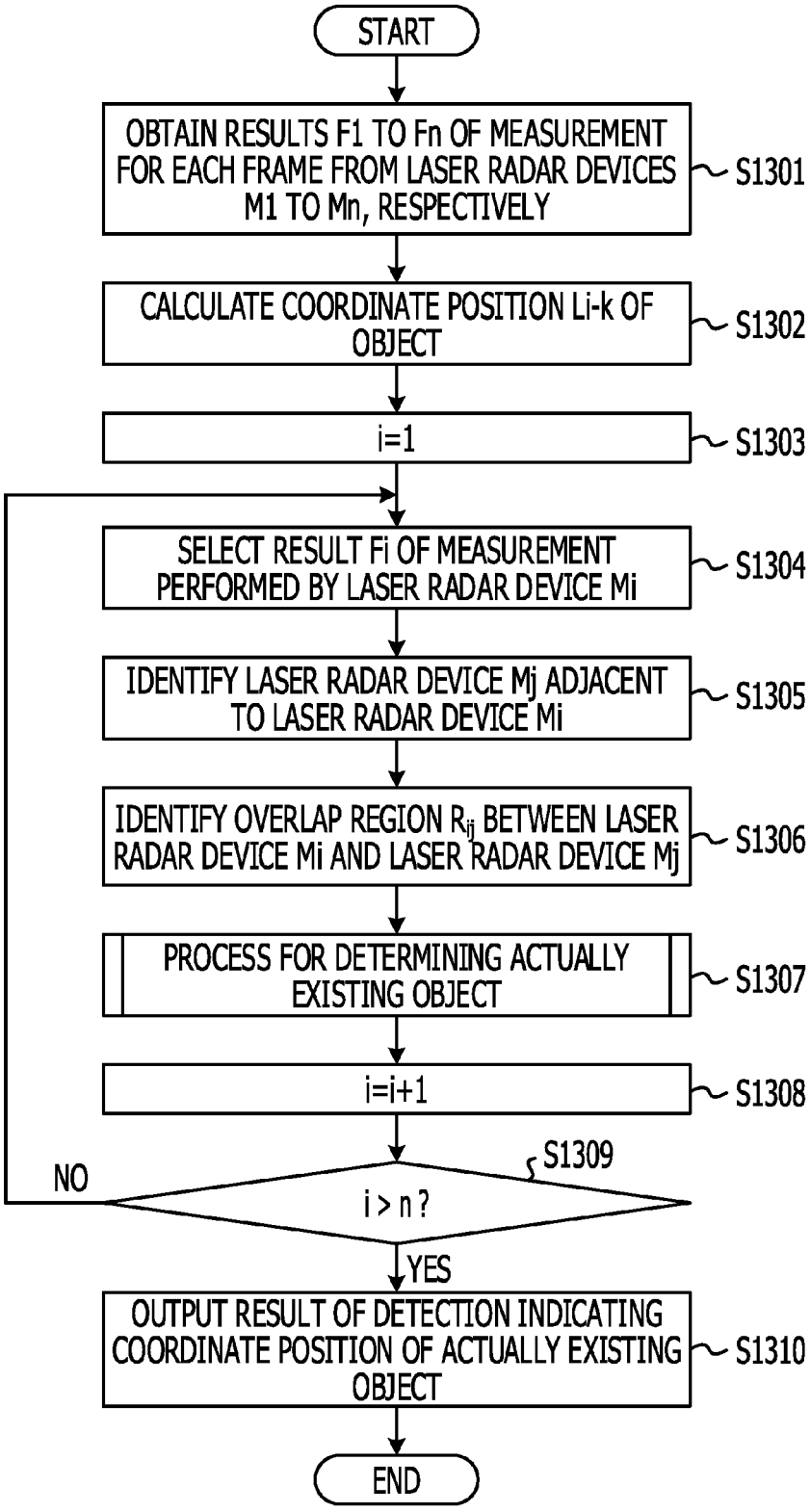
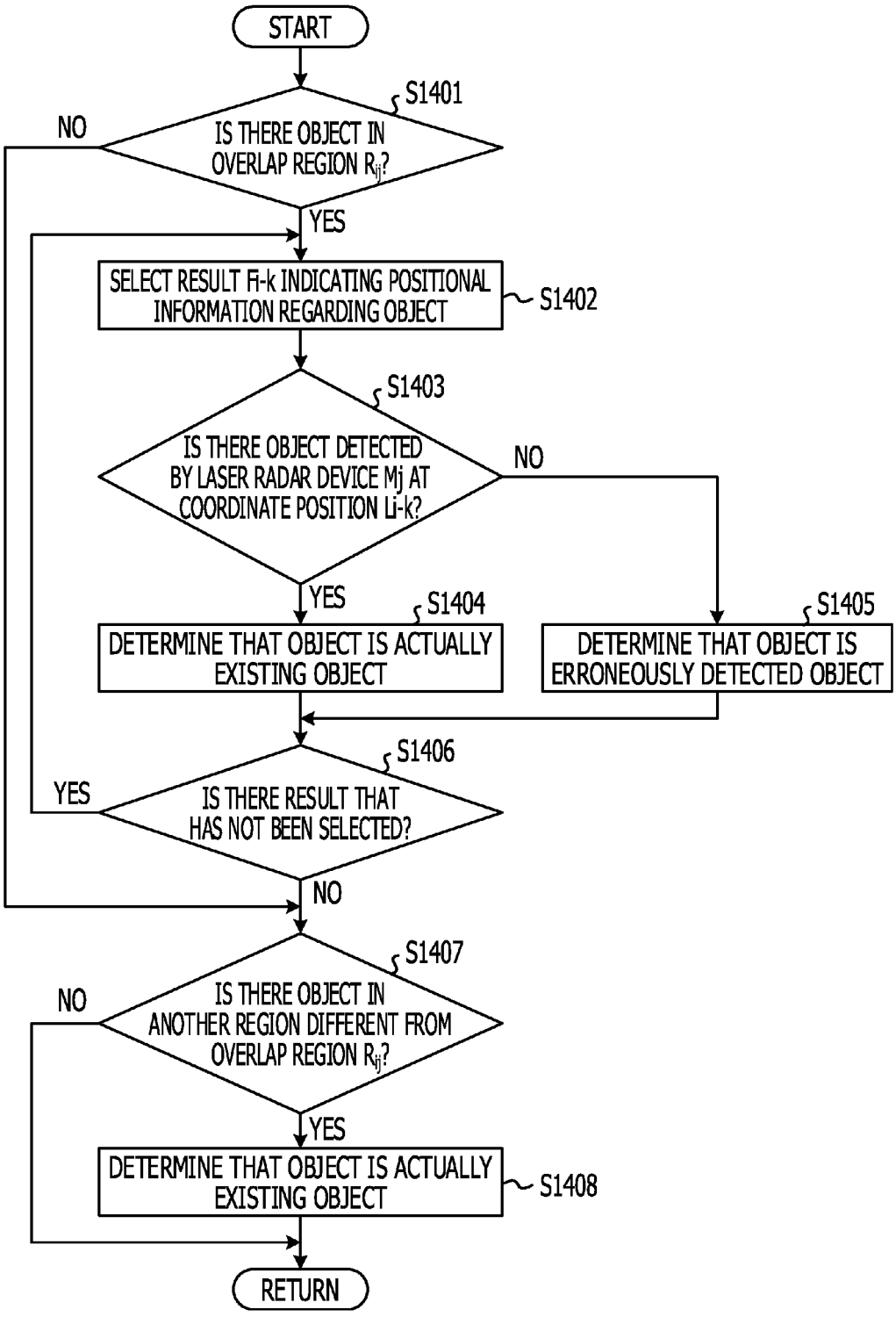

START
OBTAIN RESULTS F1 TO Fn OF MEASUREMENT FOR EACH FRAME FROM LASER RADAR DEVICES M1 TO Mn, RESPECTIVELY
S1301
CALCULATE COORDINATE POSITION Li-k OF OBJECT
S1302
i=1
S1303
SELECT RESULT Fi OF MEASUREMENT PERFORMED BY LASER RADAR DEVICE Mi
S1304
IDENTIFY LASER RADAR DEVICE Mj ADJACENT TO LASER RADAR DEVICE Mi
S1305
IDENTIFY OVERLAP REGION R_{ij} BETWEEN LASER RADAR DEVICE Mi AND LASER RADAR DEVICE Mj
S1306
PROCESS FOR DETERMINING ACTUALLY EXISTING OBJECT
S1307
i=i+1
S1308
S1309
NO
i > n ?
YES
OUTPUT RESULT OF DETECTION INDICATING COORDINATE POSITION OF ACTUALLY EXISTING OBJECT
S1310
END

FIG. 14


START
S1401
IS THERE OBJECT IN OVERLAP REGION R_{ij}?
NO
YES
SELECT RESULT Fi-k INDICATING POSITIONAL INFORMATION REGARDING OBJECT
S1402
S1403
IS THERE OBJECT DETECTED BY LASER RADAR DEVICE Mj AT COORDINATE POSITION Li-k?
NO
YES
S1404
DETERMINE THAT OBJECT IS ACTUALLY EXISTING OBJECT
S1405
DETERMINE THAT OBJECT IS ERRONEOUSLY DETECTED OBJECT
S1406
IS THERE RESULT THAT HAS NOT BEEN SELECTED?
YES
NO
S1407
IS THERE OBJECT IN ANOTHER REGION DIFFERENT FROM OVERLAP REGION R_{ij}?
NO
YES
DETERMINE THAT OBJECT IS ACTUALLY EXISTING OBJECT
S1408
RETURN

OBJECT DETECTION APPARATUS AND METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2012-196688 filed on Sep. 6, 2012, the entire contents of which are incorporated herein by reference.

FIELD

The technique disclosed in the embodiment is related to a technique for detecting an object.

BACKGROUND

In these years, laser radar devices are more and more used for monitoring the surroundings of vehicles, buildings, and the like, and especially laser radar devices capable of performing wide angle scanning using two-dimensional scanners are gaining in popularity. In addition, in order to support operation and parking of a vehicle, a system that includes a plurality of laser radar devices mounted on the vehicle and that monitors all the surroundings of the vehicle has been proposed.

As an example of the related art, a technique has been disclosed in which a control unit that controls light-emitting timings of light-emitting sources in such a way as to provide light-emitting periods in which light is emitted to target space and off periods in which light is not emitted controls the light-emitting timings such that the light-emitting periods of the light-emitting sources of detection devices do not overlap. In addition, a technique has been disclosed in which it is determined that there is an obstacle only when the obstacle has been detected by at least two of four units, that is, a pair of laser light-emitting units and a pair of ultrasonic wave transmission units, provided on the front (or the back) of a vehicle in substantially the traveling direction of the vehicle. For example, these techniques are disclosed in Japanese Laid-open Patent Publication No. 2006-300616 and Japanese Laid-open Patent Publication No. 03-164345

SUMMARY

According to an aspect of the invention, an object detection apparatus includes: a first radar configured to measure first positional information regarding a first object existing in a first scan range on the basis of first reflected wave of first wave radiated onto the first scan range including a first region; a second radar configured to measure second positional information regarding a second object existing in a second scan range on the basis of second reflected wave of second wave radiated onto the second scan range including the first region and a second region, which is located outside the first scan range, the second wave being radiated in such a way as to scan the first region in a direction opposite a direction in which the first radar radiates the first wave at a timing at which the first radar scans the first region; and a processor configured to detect a third object existing in the first region on the basis of the first positional information obtained from the first radar and the second positional information obtained from the second radar.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a diagram illustrating an object detection apparatus according to an embodiment;

FIG. **2** is a diagram illustrating an example of detection of an object around a vehicle;

FIG. **3** is a block diagram illustrating an example of the hardware configuration of the object detection apparatus;

FIG. **4** is a block diagram illustrating an example of the hardware configuration of a laser radar device;

FIG. **5** is a diagram illustrating an example of the operation of the laser radar device;

FIG. **6** is a diagram illustrating an example of the scanning order of the laser radar device;

FIG. **7** is a diagram illustrating a specific example of a result of measurement performed by the laser radar device;

FIG. **8** is a diagram illustrating a specific example of a device information table;

FIG. **9** is a diagram illustrating a specific example of an overlap region table;

FIG. **10** is a block diagram illustrating an example of the functional configuration of a control device;

FIG. **11** is a diagram illustrating an example of a determination of results of measurement for each frame;

FIG. **12** is a diagram illustrating an example of objects existing around the vehicle;

FIG. **13** is a flowchart illustrating an example of a detection processing procedure performed by the control device; and

FIG. **14** is a flowchart illustrating an example of a specific processing procedure of a process for determining an actually existing object.

DESCRIPTION OF EMBODIMENTS

Technical Problem

If a plurality of laser radar devices are used for monitoring the surroundings of a vehicle, a building, or the like in an example of the related art, an object might be erroneously detected when a certain laser radar device has received reflected light of laser light emitted from another laser radar device. For example, an object that does not actually exist might be erroneously detected when a laser radar device mounted on the left of a vehicle has received reflected light of laser light emitted by a laser radar device mounted on the front of the vehicle.

In an aspect, an object of the technique disclosed in the embodiment is to avoid erroneous detection of an object.

An object detection apparatus, an object detection program, and a vehicle according to an embodiment will be described in detail hereinafter with reference to the accompanying drawings.

Object Detection Apparatus According To Embodiment

FIG. **1** is a diagram illustrating the object detection apparatus according to the embodiment. In FIG. **1**, an object detection apparatus **100** is a computer system that detects an object existing around a vehicle, a building, or the like. The vehicle may be transportation such as, for example, a car, an

electric train, a train, or a motorcycle. The building may be a structure such as an office building, a house, or a warehouse.

With reference to FIG. **1**, an example in which the object detection apparatus **100** detects an object existing around a vehicle V will be described. The object detection apparatus **100** includes a control device **101** and laser radar devices M**1**, M**2**, M**3**, and M**4**. In the object detection apparatus **100**, the control device **101** is connected to the laser radar devices M**1** to M**4** by a wired or wireless network.

The control device **101** is a computer that detects an object on the basis of results of measurement performed by the laser radar devices M**1** to M**4**. The laser radar devices M**1** to M**4** are measuring devices that measure positional information regarding an object by scanning their respective scan ranges while intermittently emitting laser light (so-called pulse emission) and receiving reflected laser light.

More specifically, for example, the laser radar devices M**1** to M**4** scan the scan ranges while emitting pulses of laser light at the same time intervals Δt or the same angular intervals $\Delta\theta$. The time intervals Δt are time intervals at which laser light is emitted. The angular intervals AO indicate an angle (for example, a horizontal angle) between the direction of emission of laser light and the direction of next emission of laser light.

The laser radar devices M**1** to M**4** may each measure the distance to an object and the direction of the object on the basis of the time taken until reflected light is received after laser light is emitted and the emission direction of the laser light. The laser light is light amplified by stimulated emission, and has desirable directivity and convergence.

Laser light is generated by, for example, a laser oscillator that generates coherent light by amplifying light (electromagnetic wave). A scan range is a range in which scanning is performed using laser light. Scanning is to change the emission direction of laser light in a scan range. A specific example of the operation of the laser radar devices M**1** to M**4** will be described later with reference to FIG. **5**.

In the example illustrated in FIG. **1**, the laser radar device M**1** is mounted on the front of the vehicle V, the laser radar device M**2** is mounted on the right of the vehicle V, the laser radar device M**3** is mounted on the back of the vehicle V, and the laser radar device M**4** is mounted on the left of the vehicle V. The laser radar devices M**1** to M**4** are mounted on the vehicle V such that the relative positions of the laser radar devices M**1** to M**4** do not change.

In addition, the scan ranges of the laser radar devices M**1** to M**4** may be arbitrarily set. More specifically, for example, horizontal and vertical scan ranges are set to each of the laser radar devices M**1** to M**4** such that objects existing in all the surroundings of the vehicle V may be detected. The scan ranges of the laser radar devices M**1** to M**4** may be set in advance, or an operator may set the scan ranges of the laser radar devices M**1** to M**4** after mounting the laser radar devices M**1** to M**4** on the vehicle V.

In the example illustrated in FIG. **1**, for example, a scan range of "−80 [deg.] to +80 [deg.]" is set to the laser radar device M**1** as the horizontal scan range. It is assumed, however, that the traveling direction of the vehicle V is 0 [deg.], and the left to a light source (for example, a light-emitting unit **420** illustrated in FIG. **4**, which will be described later) of the laser radar device M**1** is a negative direction and the right to the light source is a positive direction.

In addition, for example, a scan range of "−80 [deg.] to +80 [deg.]" is set to the laser radar device M**2** as the horizontal scan range. It is assumed, however, that a rightward direction perpendicular to the traveling direction of the vehicle V is 0 [deg.], and the left to a light source of the laser radar device M**2** is a negative direction and the right to the light source is a positive direction.

In addition, for example, a scan range of "−80 [deg.] to +80 [deg.]" is set to the laser radar device M**3** as the horizontal scan range. It is assumed, however, that a direction opposite the traveling direction of the vehicle V is 0 [deg.], and the left to a light source of the laser radar device M**3** is a negative direction and the right to the light source is a positive direction.

In addition, for example, a scan range of "−80 [deg.] to +80 [deg.]" is set to the laser radar device M**4** as the horizontal scan range. It is assumed, however, that a leftward direction perpendicular to the traveling direction of the vehicle V is 0 [deg.], and the left to a light source of the laser radar device M**4** is a negative direction and the right to the light source is a positive direction.

Thus, by performing wide-angle scanning in a horizontal direction using laser light emitted from the laser radar devices M**1** to M**4**, blind spots around the vehicle V, in which it is difficult for the object detection apparatus **100** to detect an object, may be reduced. As with the horizontal direction, by performing wide-angle scanning in a vertical direction using laser light emitted from the laser radar devices M**1** to M**4**, blind spots around the vehicle V, in which it is difficult for the object detection apparatus **100** to detect an object, may be reduced.

The laser radar devices M**1** to M**4** receive all reflected light within their respective scan ranges. For this reason, when the laser radar devices M**1** to M**4** perform wide-angle scanning to reduce the blind spots around the vehicle V, radiation ranges in which laser light is radiated, that is, measurement ranges in which positional information regarding an object is measured, may overlap between the laser radar devices M**1**, M**2**, M**3**, and M**4**.

In the example illustrated in FIG. **1**, there is an overlap region A between a radiation range **111** of the laser light of the laser radar device M**1** and a radiation range **114** of the laser light of the laser radar device M**4**. In addition, there is an overlap region B between the radiation range **111** of the laser light of the laser radar device M**1** and a radiation range **112** of the laser light of the laser radar device M**2**.

In addition, there is an overlap region C between the radiation range **112** of the laser light of the laser radar device M**2** and a radiation range **113** of the laser light of the laser radar device M**3**. In addition, there is an overlap region D between the radiation range **113** of the laser light of the laser radar device M**3** and the radiation range **114** of the laser light of the laser radar device M**4**.

Therefore, for example, when there is an object in the overlap region A, reflected light of the laser light radiated by the laser radar device M**1** onto the object in the overlap region A might be received not only by the laser radar device M**1** but also by the laser radar device M**4**. At this time, if the direction in which the laser radar device M**4** radiates laser light is different from the direction of the overlap region A (for example, the direction of the overlap region D), an object might be erroneously detected in a region different from the overlap region A (for example, the overlap region D).

It is possible to mount a plurality of sensors of different types for detecting objects around the vehicle V in order to avoid erroneous detection of an object in a region such as the overlap region A. When sensors of different types are used, however, cost and the area occupied by the sensors undesirably increase compared to when sensors of the same type are used. In addition, it is possible to integrate a light-emitting unit and a light-receiving unit of each sensor in order to match

the emission direction and a light-receiving direction, so that each sensor may receive only reflected light from the emission direction. In this case, however, the area occupied by a driving unit that drives the light-emitting unit and the light-receiving unit undesirably increases.

Therefore, in the present embodiment, the object detection apparatus **100** causes the laser radar devices M**1** to M**4** mounted on the vehicle V to emit pulses of laser light such that timings (periods) at which adjacent laser radar devices scan the same overlap region match. The object detection apparatus **100** then detects an object existing in the overlap region between the adjacent laser radar devices on the basis of results of measurement performed by the adjacent laser radar devices.

More specifically, for example, the laser radar device M**4** scans the scan range thereof in a direction opposite the scanning direction of the laser radar device M**1** such that a timing at which the laser radar device M**4** scans the overlap region A matches with a timing at which the laser radar device M**1** scans the overlap region A. In this case, the control device **101** detects an object existing in the overlap region A on the basis of a result of measurement performed by the laser radar device M**1** and a result of measurement performed by the laser radar device M**4**.

More specifically, for example, the operator sets the scanning direction of the laser radar device M**4** to be opposite the scanning direction of the laser radar device M**1**. In addition, the operator sets the intervals (for example, the time intervals Δt and the angular intervals $\Delta\theta$) at which the laser radar device M**4** emits laser light such that the timing at which the laser radar device M**4** scans the overlap region A matches with the timing at which the laser radar device M**1** scans the overlap region A.

Alternatively, the operator may input setting information regarding the scanning direction and the emission intervals of the laser radar device M**1** and the like to the control device **101**. In this case, the control device **101** may set the scanning direction and the emission intervals of the laser radar device M**1** and the like in accordance with the input setting information.

In addition, for example, the laser radar device M**2** scans the scan range thereof in a direction opposite the scanning direction of the laser radar device M**1** such that a timing at which the laser radar device M**2** scans the overlap region B matches with a timing at which the laser radar device M**1** scans the overlap region B. In this case, the control device **101** detects an object existing in the overlap region B on the basis of a result of measurement performed by the laser radar device M**1** and a result of measurement performed by the laser radar device M**2**.

In addition, for example, the laser radar device M**3** scans the scan range thereof in a direction opposite the scanning direction of the laser radar device M**2** such that a timing at which the laser radar device M**3** scans the overlap region C matches with a timing at which the laser radar device M**2** scans the overlap region C. In this case, the control device **101** detects an object existing in the overlap region C on the basis of a result of measurement performed by the laser radar device M**2** and a result of measurement performed by the laser radar device M**3**.

Furthermore, for example, the laser radar device M**3** scans the scan range thereof in a direction opposite the scanning direction of the laser radar device M**4** such that a timing at which the laser radar device M**3** scans the overlap region D matches with a timing at which the laser radar device M**4** scans the overlap region D. In this case, the control device **101** detects an object existing in the overlap region D on the basis of a result of measurement performed by the laser radar device M**3** and a result of measurement performed by the laser radar device M**4**.

Now, an example of detection of an object existing around the vehicle V will be described.

FIG. **2** is a diagram illustrating an example of detection of an object existing around the vehicle V. Here, an example of detection of an object existing in the overlap region A will be described while taking the laser radar devices M**1** and M**4** mounted on the vehicle V as an example.

(1) The control device **101** obtains a result **210** of measurement performed by the laser radar device M**1**. In the example illustrated in FIG. **2**, the control device **101** determines from the result **210** of the measurement performed by the laser radar device M**1** that objects **201** and **202** have been detected in the overlap region A.

(2) The control device **101** obtains a result **220** of measurement performed by the laser radar device M**4**. In the example illustrated in FIG. **2**, the control device **101** determines from the result **220** of the measurement performed by the laser radar device M**4** that objects **203** and **204** have been detected in the overlap region A. It is to be noted that the results **210** and **220** are obtained by the laser radar devices M**1** and M**4**, respectively, at the same timing.

(3) The control device **101** determines whether or not the absolute coordinates of the objects (objects **201** and **202**) identified from the result **210** match with the absolute coordinates of the objects (objects **203** and **204**) identified from the result **220**. If the absolute coordinates of the objects match, the control device **101** detects objects existing in the overlap region A. The absolute coordinates are, for example, a coordinate position represented by a distance from the center of the vehicle V.

In the example illustrated in FIG. **2**, the absolute coordinates of the object **201** and the absolute coordinates of the object **203** match. Therefore, the control device **101** detects the object **201** (object **203**) as an object existing in the overlap region A. The object **202** is an object erroneously detected by the laser radar device M**1** by receiving reflected light that is originally emitted from the laser radar device M**4** and reflected from the object **201** (object **203**). The object **204** is an object erroneously detected by the laser radar device M**4** by receiving reflected light that is originally emitted from the laser radar device M**1** and reflected from the object **201** (object **203**).

Thus, according to the object detection apparatus **100**, it is possible to avoid erroneous detection of an object in an overlap region between adjacent two of the laser radar devices M**1** to M**4** mounted on the vehicle V. More specifically, for example, the scan ranges of the laser radar devices M**1** and M**4** may be scanned in opposite directions such that the timing at which the laser radar device M**4** scans the overlap region A matches with the timing at which the laser radar device M**1** scans the overlap region A.

In doing so, the laser radar devices M**1** and M**4** may intentionally detect objects erroneously detected by receiving reflected light of laser light emitted from the adjacent laser radar devices in the overlap region A. As a result, by comparing results of measurement of an overlap region between adjacent laser radar devices, it is possible to determine that an object detected by both the adjacent laser radar devices is an actually existing object and objects other than the foregoing object as erroneously detected objects.

In addition, by avoiding erroneous detection of an object in the overlap regions between adjacent laser radar devices, the laser radar devices M**1** to M**4** may perform scanning at wider

angles using laser light and the blind spots around the vehicle V may be reduced, thereby providing a safer monitoring system.

Although a vehicle has been taken as an example of transportation (moving body) to which the object detection apparatus **100** is applied in the above description, the technique disclosed herein is not limited to this. For example, the object detection apparatus **100** may be applied to a moving body such as an airplane, a helicopter, or a ship, for whose operator there are blind spots. In addition, instead of the laser radar devices M1 to M4, measuring devices that measure the distances to objects and the directions of the objects by radiating ultrasonic waves and receiving reflected waves of the ultrasonic waves may be used.

(Example of Hardware Configuration of Object Detection Apparatus **100**)

FIG. **3** is a block diagram illustrating an example of the hardware configuration of the object detection apparatus **100**. In FIG. **3**, the object detection apparatus **100** includes the control device **101** and laser radar devices M1 to Mn (n is a natural number equal to or larger than 2; n=4 in the example illustrated in FIG. **1**). In the following description, an arbitrary one of the laser radar devices M1 to Mn may be referred to as a "laser radar device Mi" (i=1, 2, . . . , or n).

The control device **101** includes a central processing unit (CPU) **301**, a memory **302**, an interface (I/F) **303**, and a graphics display controller (GDC) **304**. The components are connected to one another by a bus **310**.

The CPU **301** controls the entirety of the control device **101**. The memory **302** includes, for example, a read-only memory (ROM), a random-access memory (RAM), and a flash ROM. More specifically, for example, the flash ROM stores programs such as an operating system (OS) and firmware, the ROM stores application programs, and the RAM is used as a work area of the CPU **301**. The programs stored in the memory **302** cause the CPU **301** to execute coded processes when loaded into the CPU **301**.

The I/F **303** controls input and output of data to and from external devices (for example, the laser radar devices M1 to Mn). More specifically, for example, the I/F **303** is connected to the wired or wireless network, and connected to the external devices through the network. The I/F **303** serves as an interface between the network and the inside of the control device **101**, and controls input and output of data to and from the external devices.

The GDC **304** is a controller that performs a rendering process for a display **320**. According to the GDC **304**, the processing load on the CPU **301** caused by the rendering process may be reduced. The display **320** may, for example, be included in the object detection apparatus **100**, or may be mounted on an in-vehicle device such as a navigation device, instead.

In addition to the above-described components, the object detection apparatus **100** may include, for example, an input device that inputs data such as characters, numbers, and various instructions. Alternatively, among the above-described components, the object detection apparatus **100** does not have to include the GDC **304**. Next, a specific example of the hardware configuration of the laser radar device Mi will be described.

FIG. **4** is a block diagram illustrating an example of the hardware configuration of the laser radar device Mi. In FIG. **4**, the laser radar device Mi includes a control unit **410**, the light-emitting unit **420**, and a light-receiving unit **430**. The control unit **410** controls the entirety of the laser radar device Mi. The light-emitting unit **420** emits laser light. The light-receiving unit **430** receives reflected light of the laser light.

More specifically, the control unit **410** includes a CPU **411**, a control circuit **412**, a laser oscillation circuit **413**, a beam deflection element driving circuit **414**, a light-receiving circuit **415**, and a time measurement circuit **416**. The light-emitting unit **420** includes a mirror **421** and a laser **422**. The light-receiving unit **430** includes an avalanche photodiode (APD) **431**.

The CPU **411** controls the entirety of the control unit **410**. The control circuit **412** transmits timing signals of laser pulses to the laser oscillation circuit **413** and a start signal to the time measurement circuit **416** in accordance with the control performed by the CPU **411**. In addition, the control circuit **412** transmits signals regarding scanning order to the beam deflection element driving circuit **414** in synchronization with the timing signals of laser pulses in order to drive the mirror **421** of the light-emitting unit **420**.

The laser **422** emits laser light. The laser light emitted from the light-emitting unit **420** and reflected from an object (reflected light) is received by the light-receiving circuit **415** through the APD **431** of the light-receiving unit **430**. Upon receiving the reflected light, the light-receiving circuit **415** transmits a stop signal to the time measurement circuit **416**. The CPU **411** calculates a distance on the basis of a time difference ΔT between the start signal and the stop signal of laser pulses received by the time measurement circuit **416**.

More specifically, for example, the CPU **411** may calculate a distance Z to a target (object) using the following expression (1). Here, c denotes the speed of light (for example, c≈300,000 [km/s]).

$$Z=(c\times\Delta T)/2 \quad (1)$$

(Example of Operation of Laser Radar Device Mi)

Next, a specific example of the operation of the laser radar device Mi will be described. FIG. **5** is a diagram illustrating an example of the operation of the laser radar device Mi. In FIG. **5**, the light-emitting unit **420** and the light-receiving unit **430** of the laser radar device Mi are illustrated. In the example illustrated in FIG. **5**, a near-infrared laser is used as the laser **422**, and a combination between a microelectromechanical systems (MEMS) mirror and a galvanometer mirror is used as the mirror **421**.

For example, the laser radar device Mi may horizontally change the emission direction of laser light using the MEMS mirror and vertically change the emission direction of laser light using the galvanometer mirror, in order to realize a two-dimensional scan range. Alternatively, the laser radar device Mi may realize the two-dimensional scan range by combining two MEMS mirrors or using a single MEMS mirror with which two-dimensional scanning may be performed.

The laser light emitted from the laser **422** is incident on the mirror **421** through a collimator lens **501**. The laser light reflected from the mirror **421** is emitted from the light-emitting unit **420** through a scanning angle increasing lens **502**. The laser light emitted from the light-emitting unit **420** is reflected from a target **503**, and then received by the APD **431** through a light-receiving lens **504** of the light-receiving unit **430**.

(Example of Scanning Order of Laser Radar Device Mi)

Here, an example of the scanning order of the laser radar device Mi will be described. FIG. **6** is a diagram illustrating an example of the scanning order of the laser radar device Mi. In FIG. **6**, an example of scanning order in which the laser radar device Mi scans the scan range thereof is illustrated. In FIG. **6**, each hollow circle represents one operation for emitting laser light performed by the laser radar device Mi.

More specifically, when scanning has begun and horizontal scanning in a first row has been completed, the laser radar device Mi returns to a right end while moving up to a next row, and performs horizontal scanning in a second row. When horizontal scanning in a k-th row has been completed, the laser radar device Mi ends the scanning.

In the following description, a group of results obtained by scanning the entirety of the scan range of the laser radar device Mi may be referred to as "a result of measurement for each frame".

(Specific Example of Result of Measurement Performed by Laser Radar Device Mi)

Next, a result of measurement performed by the laser radar device Mi will be described. FIG. **7** is a diagram illustrating a specific example of a result of measurement performed by the laser radar device Mi. In FIG. **7**, a result **700** of measurement is information indicating a device identifier (ID), emission angles (X, Y), and the distance Z.

Here, the device ID is identification information regarding the laser radar device Mi. The emission angles indicate the emission direction of laser light, and represent a direction in which a target exists relative to the laser radar device Mi. X denotes the horizontal emission angle [deg.] of laser light, and Y denotes the vertical emission angle [deg.] of laser light. The distance Z is a distance from the laser radar device Mi to the target. The distance Z is, for example, a value calculated by using the above expression (1).

According to the result **700** of measurement, it is possible to identify a target located 3 m away from the laser radar device M**1** in a direction of emission angles (−50 [deg.], −15 [deg.]).

Alternatively, the result **700** of measurement may include time information for identifying a time at which the result **700** of measurement has been obtained. The time information indicates, for example, a time at which a start signal has been received by the time measurement circuit **416** (refer to FIG. **4**) or a time at which a stop signal has been received by the time measurement circuit **416**. Alternatively, the result **700** of measurement may include, instead of the distance Z, the time at which a start signal has been received by the time measurement circuit **416** and the time at which a stop signal has been received by the time measurement circuit **416** or the time difference ΔT.

(Specific Example of Device Information Table **800**)

Next, a device information table **800** used by the control device **101** will be described. The device information table **800** is, for example, stored in the memory **302** of the control device **101** illustrated in FIG. **3**.

FIG. **8** is a diagram illustrating a specific example of the device information table **800**. In FIG. **8**, the device information table **800** includes fields of device ID, mounted position, adjacent device IDs, and overlap regions A to D. By setting information in each field, device information **800-1** to **800-4** regarding the laser radar devices M**1** to M**4**, respectively, is stored as a record.

Here, the device ID is identification information regarding the laser radar device Mi. The mounted position is absolute coordinates representing the coordinate position of the laser radar device Mi mounted on the vehicle V relative to the center of the vehicle V. The adjacent device IDs are identification information regarding laser radar devices adjacent to the laser radar device Mi, that is, laser radar devices whose radiation regions overlap the radiation region of the laser radar device Mi. The overlap regions A to D are information for identifying overlap regions between the laser radar device Mi and adjacent laser radar devices.

For example, according to the device information **800-1**, the mounted position (sx**1**, sy**1**, sz**1**) of the laser radar device M**1** and the adjacent device IDs "M**2**, M**4**" regarding the laser radar devices M**2** and M**4**, which are located adjacent to the laser radar device M**1**, may be identified. In addition, it may be identified that the radiation region of the laser radar device M**1** and the radiation region of the laser radar device M**4** overlap in the overlap region A. In addition, it may be identified that the radiation region of the laser radar device M**1** and the radiation region of the laser radar device M**2** overlap in the overlap region B.

(Overlap Region Table **900**)

Next, an overlap region table **900** used by the control device **101** will be described. The overlap region table **900** is, for example, stored in the memory **302** of the control device **101**.

FIG. **9** is a diagram illustrating a specific example of the overlap region table **900**. In FIG. **9**, the overlap region table **900** includes fields of region ID, device IDs, horizontal angular range, and vertical angular range. By setting information in each field, overlap region information **900-1** to **900-4** regarding the overlap regions A to D, respectively, is stored as a record.

Here, the region ID is identification information regarding an overlap region. The device IDs are identification information regarding laser radar devices that share an overlap region. The horizontal angular range indicates a horizontal angular range relative to the laser radar device Mi in which an overlap region exists. The vertical angular range indicates a vertical angular range relative to the laser radar device Mi in which an overlap region exists.

For example, according to the overlap region information **900-1**, the device IDs "M**1**, M**4**" regarding laser radar devices that share the overlap region A may be identified. In addition, the horizontal angular range "$\theta 1 \leq \theta \leq 2$" and the vertical angular range "$\phi 1 \leq \phi \leq \phi 2$" relative to the laser radar device M**1** in which the overlap region A exists may be identified. The horizontal angular range "$\theta 3 \leq \theta \leq \theta 4$" and the vertical angular range "$\phi 3 \leq \phi \leq \phi 4$" relative to the laser radar device M**4** in which the overlap region A exists may be identified.

The overlap region information **900-1** to **900-4** may be directly input to the control device **101** by an operation performed by the operator, or may be created by the control device **101** on the basis of the scan ranges of the laser radar devices M**1** to M**4**.

(Example of Functional Configuration of Control Device **101**)

Next, an example of the functional configuration of the control device **101** of the object detection apparatus **100** will be described. FIG. **10** is a block diagram illustrating an example of the functional configuration of the control device **101**. In FIG. **10**, the control device **101** includes an obtaining unit **1001**, a calculation unit **1002**, a determination unit **1003**, a detection unit **1004**, and an output unit **1005**. The obtaining unit **1001** to the output unit **1005** are functions that serve as control units. More specifically, for example, the functions are realized by causing the CPU **301** to execute the programs stored in the memory **302** illustrated in FIG. **3** or by the I/F **303**. Results of processing performed by these function units are, for example, stored in the memory **302**.

In the following description, a laser radar device adjacent to the laser radar device Mi may be referred to as a "laser radar device Mj" ($i \neq j$ and $j=1, 2, \ldots$, or n). An overlap region in which the radiation region of the laser radar device Mi and the radiation region of the laser radar device Mj may be referred to as an "overlap region R_{ij}".

The obtaining unit **1001** has a function of obtaining a result Fi of measurement performed by the laser radar device Mi from the laser radar device Mi. The result Fi includes positional information regarding an object measured by the laser radar device Mi. The positional information regarding an object is, for example, information indicating the direction (the horizontal angle X and the vertical angle Y) of the object and the distance Z to the object from the laser radar device Mi. The result Fi is, for example, the result **700** illustrated in FIG. **7**.

More specifically, for example, the obtaining unit **1001** obtains the result Fi transmitted from the laser radar device Mi each time the laser radar device Mi obtains the result Fi. When the positional information regarding an object has not been obtained by the laser radar device Mi, the result Fi is information indicating that an object has not been detected.

The calculation unit **1002** has a function of calculating a coordinate position Li of an object on the basis of the result Fi obtained by the laser radar device Mi. Here, the coordinate position Li of an object is, for example, absolute coordinates indicating a distance from an origin to the object in a spatial coordinate system (three-dimensional Cartesian coordinate system) defined by a dX axis (horizontal angle), a dY axis (vertical angle), and a dZ angle (distance).

For example, in the case of the laser radar device Mi mounted on the front of the vehicle V, the origin (0, 0, 0) in the spatial coordinate system is the center of the vehicle V. The dX axis of the spatial coordinate system is, for example, a rightward axis passing through the origin and perpendicular to the traveling direction of the vehicle V. The dY axis of the spatial coordinate system is, for example, a vertical axis passing through the origin. The dZ axis of the spatial coordinate system is, for example, an axis in the traveling direction passing through the origin. The dX axis and the dY axis change depending on the direction (forward, backward, rightward, or leftward) of the laser radar device Mi.

More specifically, for example, first, the calculation unit **1002** corrects the coordinates of the result Fi of the measurement from the mounted position of the laser radar device Mi to the origin (the center of the vehicle V) using the following expressions (2), (3), and (4). Here, (X [deg.], Y [deg.], Z [m]) indicates the direction (the horizontal angle Z and the vertical angle Y) of an object and the distance Z to the object identified from the result Fi of the measurement performed by the laser radar device Mi. (sx [m], sy [m], sz [m]) indicates the mounted position of the laser radar device Mi. (x' [m], y' [m], z' [m]) indicates coordinates obtained as a result of the correction.

$$x' = Z \cdot \cos Y \cdot \sin X + sx \quad (2)$$

$$y' = Z \cdot \cos Y \cdot \sin Y + sy \quad (3)$$

$$z' = Z \cdot \cos Y \cdot \cos X + sz \quad (4)$$

Next, the calculation unit **1002** calculates the absolute coordinates of the object using the following expressions (5), (6), and (7). Here, (dX [deg.], dY [deg.], dZ [m]) is the absolute coordinates of the object relative to the origin, which is the center of the vehicle V.

$$dX = \arctan(x'/z') \quad (5)$$

$$dY = \arctan(y'/z') \quad (6)$$

$$dZ = z'/\{\cos(dX) \cdot \cos(dY)\} \quad (7)$$

Now, the mounted position (sx**1**, sy**1**, sz**1**) of the laser radar device M**1** is assumed to be (0, 0, 2), and an example of calculation of the absolute coordinates of an object will be described while taking the result **700** illustrated in FIG. **7** as an example.

First, the calculation unit **1002** substitutes "(X, Y, Z)=(−50, −15, 3)" indicated by the result **700** for the above expressions (2) to (4) in order to calculate the coordinates (x', y', z') obtained as a result of the correction. Results of the calculation are as follows.

$$x' = 3 \cdot \cos(-15) \cdot \sin(-50) + 0 = -2.22 \text{ [m]}$$

$$y' = 3 \cdot \cos(-50) \cdot \sin(-15) + 0 = -0.50 \text{ [m]}$$

$$z' = 3 \cdot \cos(-15) \cdot \cos(-50) + 2 = 3.86 \text{ [m]}$$

The calculation unit **1002** then substitutes "(x', y', z')=(−2.22, −0.50, 3.86)", which are the coordinates obtained as a result of the correction, for the above expressions (5) to (7) in order to calculate the absolute coordinates (dX, dY, dZ) of the object. Results of the calculation are as follows.

$$dX = \arctan(-2.22/3.86) = -29.90 \text{ [deg.]}$$

$$dY = \arctan(-0.50/3.86) = -7.38 \text{ [deg.]}$$

$$dZ = 3.86/\{\cos(-29.90) \cdot \cos(-7.38)\} = 4.49 \text{ [m]}$$

When the forward direction of the vehicle V is assumed to be 0 [deg.] and the angle is assumed to increase up to 360 [deg.] in clockwise rotation, for example, dX=360−29.90=330.1 [deg.] (the absolute coordinates relative to the center of the vehicle V are X=330.1 [deg.], Y=−7.38 [deg.], and Z=4.49 [m]).

Now, an example of calculation of the absolute coordinates of the object will be described while assuming the mounted position (sx**4**, sy**4**, sz**4**) of the laser radar device M**4** to be (1, 0.5, 1) and a result F**4** of measurement performed by the laser radar device M**4** to be "(X, Y, Z)=(20, −5, 5)".

First, the calculation unit **1002** substitutes "(X, Y, Z)=(20, −5, 5)" indicated by the result F**4** for the above expressions (2) to (4) in order to calculate (x', y', z'), which is coordinates obtained as a result of correction. Results of the calculation are as follows.

$$x' = 5 \cdot \cos(-5) \cdot \sin(20) + 1 = 2.70 \text{ [m]}$$

$$y' = 5 \cdot \cos(20) \cdot \sin(-5) + 0.5 = 0.09 \text{ [m]}$$

$$z' = 5 \cdot \cos(-5) \cdot \cos(20) + 1 = 5.68 \text{ [m]}$$

The calculation unit **1002** then substitutes "(x', y', z')=(2.70, 0.09, 5.68)", which is the coordinates obtained as a result of the correction, for the above expressions (5) to (7) in order to calculate the absolute coordinates (dX, dY, dZ) of the object. Results of the calculation are as follows.

$$dX = \arctan(2.70/5.68) = 25.42 \text{ [deg.]}$$

$$dY = \arctan(0.09/5.68) = 0.91 \text{ [deg.]}$$

$$dZ = 5.68/\{\cos(25.42) \cdot \cos(0.91)\} = 6.29 \text{ [m]}$$

When the forward direction of the vehicle V is assumed to be 0 [deg.] and the angle is assumed to increase up to 360 [deg.] in clockwise rotation, for example, dX=270+25.42=295.42 [deg.] (the absolute coordinates relative to the center of the vehicle V are X=295.42 [deg.], Y=0.91 [deg.], and Z=6.29 [m]).

The result Fi may include, instead of the distance Z, a time at which a start signal has been received by the time measurement circuit **416** and a time at which a stop signal has been received by the time measurement circuit **416** or the time difference ΔT. In this case, for example, the calculation unit

1002 may calculate the distance Z to the object using the above expression (1). The calculated coordinate position Li of the object is, for example, associated with the result Fi and stored in the memory 302.

The determination unit 1003 has a function of determining whether or not the coordinate position Li of an object obtained from the result Fi of measurement of the overlap region R_{ij} performed by the laser radar device Mi and a coordinate position Lj of an object identified from a result Fj of measurement of the overlap region R_{ij} performed by the laser radar device Mj match.

More specifically, for example, the determination unit 1003 compares the coordinate positions Li and Lj of objects obtained from the results Fi and Fj of measurement performed by the laser radar devices Mi and Mj, respectively, at the same time. The measurement time of the result Fi may be, for example, identified from the time information included in the result Fi.

When the laser radar devices Mi and Mj scan the same scan range (the same horizontal angular range and the same vertical angular range) at the same emission intervals, the determination unit 1003 may compare the results Fi and Fj themselves sequentially transmitted from the laser radar devices Mi and Mj, respectively.

At this time, the determination unit 1003 may determine that the coordinate positions Li and Lj of objects match when the coordinate positions Li and Lj of objects perfectly match. Alternatively, the determination unit 1003 may determine that the coordinate positions Li and Lj of objects match when a difference between the coordinate positions Li and Lj of objects is within a predetermined range.

Here, for example, "i" of the laser radar device Mi is assumed to be "1". In this case, for example, the determination unit 1003 refers to the device information table 800 (refer to FIG. 8) and identifies the laser radar device M4 (j=4) adjacent to the laser radar device M1. In addition, the determination unit 1003 refers to the device information table 800 and identifies the overlap region A (R_{ij}=A) between the laser radar device M1 and the laser radar device M4.

Next, the determination unit 1003 refers to the overlap region information 900-1 in the overlap region table 900 and identifies the result F1 of measurement of the overlap region A performed by the laser radar device M1. In addition, the determination unit 1003 refers to the overlap region information 900-1 in the overlap region table 900 and identifies the result F4 of measurement of the overlap region A performed by the laser radar device M4.

The determination unit 1003 then determines whether or not the coordinate position L1 of an object obtained from the identified result F1 of measurement of the overlap region A and the coordinate position L4 of an object identified from the result F4 of measurement of the overlap region A match. The coordinate position Li of an object is, for example, the absolute coordinates of an object calculated by the calculation unit 1002.

The detection unit 1004 has a function of detecting an object existing in the overlap region R_{ij} on the basis of a result of a determination made by the determination unit 1003. More specifically, for example, the detection unit 1004 detects an object existing in the overlap region R_{ij} when the determination unit 1003 has determined that the coordinate positions Li and Lj of objects match. On the other hand, when it has been determined that the coordinate positions Li and Lj of objects do not match, the detection unit 1004 determines that the objects identified from the results Fi and Fj are erroneously detected objects.

Alternatively, the detection unit 1004 may detect an object existing in another region AR different from the overlap region R_{ij} on the basis of the result Fi of measurement of the other region AR performed by the laser radar device Mi. More specifically, for example, the detection unit 1004 detects an object identified from the result Fi of measurement of the other region AR.

The output unit 1005 has a function of outputting a result of detection performed by the detection unit 1004. More specifically, for example, the output unit 1005 may output information indicating that there is an object in the overlap region R_{ij} (for example, a region located ahead of a left part of the vehicle V). Alternatively, the output unit 1005 may output information indicating that there is an object in the other region AR (for example, a region located to the left of the vehicle V) different from the overlap region R_{ij}.

In addition, the output unit 1005 may output the coordinate position Li (absolute coordinates) of an object existing in the overlap region R_{ij}. Alternatively, the output unit 1005 may output the coordinate position Li (absolute coordinates) of an object existing in the other region AR different from the overlap region R_{ij}. In addition, the output unit 1005 may create a three-dimensional image of space around the vehicle V on the basis of the detected result, and output the three-dimensional image to the display 320.

The control device 101 may, for example, receive setting information regarding the laser radar device Mi through an input operation performed by a user using an input apparatus, which is not illustrated. Here, the setting information includes information for scanning the scan range such that the scan ranges of adjacent laser radar devices are scanned in opposite directions (opposite phases) and timings at which the adjacent laser radar devices scan the overlap region match. More specifically, for example, the setting information is information indicating the scan range, the scanning direction, the scanning speed, and the emission intervals of the laser radar device Mi and the like.

In addition, the control device 101 may communicate with the laser radar device Mi and set the scan range, the scanning direction, the emission intervals, and the emission timings of the laser radar device Mi and the like on the basis of the received setting information regarding the laser radar device Mi.

More specifically, for example, the same scan range (the same horizontal angular range and the same vertical angular range) and the same emission intervals are set to the laser radar devices M1 to Mn. In addition, a scanning direction opposite the scanning direction of the adjacent laser radar device Mj is set to the laser radar device Mi. The emission intervals are, for example, specified by the time intervals Δt or the angular intervals $\Delta\theta$.

That is, the control device 101 sets various pieces of scan information to the laser radar device Mi such that the laser radar devices M1 to Mn scan their respective scan ranges in the same period. In the laser radar device Mi, the control unit 410 controls the light-emitting unit 420 in accordance with the set pieces of scan information in order to perform scanning using laser light.

Thus, the control device 101 may obtain results of measurement performed by the laser radar devices M1 to Mn at the same time by instructing the laser radar devices M1 to Mn to perform scanning using laser light at the same timing.

When the horizontal angular range of the scan range is different between adjacent laser radar devices, the time taken to horizontally scan one line is different, and accordingly the timing at which the overlap region is scanned is different. In this case, for example, the control device 101 may adjust the

emission intervals of the laser radar device Mj in accordance with the laser radar device Mi that takes longer time to scan one line.

For example, the horizontal angular range of the laser radar device M1 is set to "−80 [deg.] to +80 [deg.]", and the horizontal angular range of the laser radar device M4 is set to "−60 [deg.] to +60 [deg.]". The laser radar devices M1 and M4 are assumed to emit laser light while horizontally moving by one degree at intervals of 1 second.

That is, the laser radar device M1 takes 160 seconds to scan one line, whereas the laser radar device M4 takes 120 seconds to scan one line. In this case, for example, the control device **101** may match the periods in which the laser radar devices M1 and M4 scan one line by adjusting the emission intervals of the laser radar device M4 such that the laser radar device M4 emits laser light while horizontally moving by one degree at intervals of 4/3 seconds.

(Example of Determination Using Result of Measurement for Each Frame)

Next, an example of a determination as to whether or not the coordinate position Li of an object and the coordinate position Lj of an object match using a result of measurement for each frame performed by the laser radar device Mi will be described.

FIG. **11** is a diagram illustrating an example of a determination using results of measurement for each frame. In FIG. **11**, a result **1110** is a result of measurement for each frame performed by the laser radar device Mi (front of the vehicle V). A result **1120** is a result of measurement for each frame performed by the laser radar device M4 (left of the vehicle V).

In FIG. **11**, solid circles indicate results of measurement in which positional information regarding an object has been obtained. In FIG. **11**, hollow circles indicate results of measurement in which positional information regarding an object has not been obtained. The results **1110** and **1120** are obtained by the laser radar devices M1 and M4, respectively, in the same period. Results of measurement included in a broken-line frame **1130** indicate results of measurement of the overlap region A of the result **1110**. Results of measurement included in a broken-line frame **1140** indicate results of measurement of the overlap region A of the result **1120**.

In this case, for example, the determination unit **1003** determines whether or not the coordinate positions of objects obtained from results p**1**, p**2**, p**3**, p**4**, p**5**, p**6**, p**7**, and p**8** included in the broken-line frame **1130** and the coordinate positions of objects obtained from results q**1**, q**2**, q**3**, q**4**, q**5**, q**6**, q**7**, and q**8** included in the broken-line frame **1140** match.

Now, assume that the coordinate position of an object obtained from the result p**1** and the coordinate position of an object identified from the result q**1** match. In this case, the detection unit **1004** determines that there is an object at the coordinate position obtained from the result p**1** (result q**1**). In addition, assume that the coordinate position of an object obtained from the result p**2** and the coordinate position of an object identified from the result q**2** match. In this case, the detection unit **1004** determines that there is an object at the coordinate position obtained from the result p**2** (result q**2**).

In addition, assume that the coordinate position of an object obtained from the result p**3** and the coordinate position of an object identified from the result q**3** match. In this case, the detection unit **1004** determines that there is an object at the coordinate position obtained from the result p**3** (result q**3**). In addition, assume that the coordinate position of an object obtained from the result p**4** and the coordinate position of an object identified from the result q**4** match. In this case, the detection unit **1004** determines that there is an object at the coordinate position obtained from the result p**4** (result q**4**).

An actual object is not a point but has volume, and, for example, recognized as having a shape according to an angle and a distance between adjacent results. Therefore, in the example illustrated in FIG. **11**, objects OB**1** and OB**2** are recognized in the result **1110**, and objects OB**3** and OB**4** are recognized in the result **1120**. On the basis of the above-described results, the objects OB**1** and OB**3** (actually a single object) are determined as actually existing objects, and the objects OB**2** and OB**4** are determined as erroneously detected objects.

(Example of Objects in Three-Dimensional Space)

FIG. **12** is a diagram illustrating an example of objects existing around the vehicle V. In FIG. **12**, the objects OB**1** to OB**4** existing around the vehicle V are indicated in a spatial coordinate system **1200**. As described above, the object OB**1** (object OB**3**) is an actually existing object, and the objects OB**2** and OB**4** are erroneously detected objects.

(Detection Processing Procedure Performed by Control Device **101**)

Next, a detection processing procedure performed by the control device **101** according to the embodiment will be descried. Here, the detection processing procedure performed by the control device **101** that detects objects existing around the vehicle V on the basis of a result of measurement for each frame performed by the laser radar device Mi will be described.

In the following description, a result of measurement for each frame performed by the laser radar device Mi may be referred to as a "result Fi". In addition, a plurality of results included in the result Fi may be referred to as "results Fi-1 to Fi-K", and an arbitrary one of the results Fi-1 to Fi-K may be referred to as a "result Fi-k" (k=1, 2, . . . , or K).

FIG. **13** is a flowchart illustrating an example of the detection processing procedure performed by the control device **101**. In the flowchart of FIG. **13**, first, the control device **101** obtains results F**1** to Fn for each frame from the laser radar devices M**1** to Mn, respectively (step S**1301**). Here, the results F**1** to Fn are results of measurement performed by the laser radar devices M**1** to Mn, respectively, in the same period.

Next, the control device **101** calculates a coordinate position Li-k of an object on the basis of a result Fi-k included in the obtained result Fi and the mounted position of the laser radar device Mi (step S**1302**). However, a result Fi-k indicating that no object has been detected is not used to calculate the coordinate position of an object.

Next, the control device **101** determines "i" of the laser radar device Mi as "1" (step S**1303**), and selects the result Fi of measurement performed by the laser radar device Mi among the laser radar devices M**1** to Mn (step S**1304**).

The control device **101** then refers to the device information table **800** and identifies the laser radar device Mj adjacent to the laser radar device Mi (step S**1305**). Next, the control device **101** refers to the device information table **800** and identifies the overlap region overlap region R_{ij} between the laser radar device Mi and the laser radar device Mj (step S**1306**).

The control device **101** then executes a process for determining an actually existing object (step S**1307**). A specific processing procedure of the process for determining an actually existing object will be described later with reference to FIG. **14**. Next, the control device **101** increases "i" of the laser radar device Mi by 1 (step S**1308**), and determines whether or not "i" has become larger than "n" (step S**1309**).

If "i" is smaller than or equal to "n" (NO in step S**1309**), the control device **101** causes the procedure to return to step S**1304**. On the other hand, if "i" is larger than "n" (YES in

S1309), the control device **101** outputs a result of detection indicating the coordinate position of an actually existing object (step S1310), and ends the procedure illustrated in the flowchart.

FIG. **14** is a flowchart illustrating an example of a specific processing procedure of the process for determining an actually existing object. In the flowchart of FIG. **14**, first, the control device **101** determines whether or not there is an object in the overlap region R_{ij} on the basis of the result Fi of measurement performed by the laser radar device Mi (step S1401).

Here, if there is no object in the overlap region R_{ij} (NO in step S1401), the control device **101** causes the process to proceed to step S1407. On the other hand, if there is an object in the overlap region R_{ij} (YES in step S1401), the control device **101** selects a result Fi-k indicating positional information regarding the object that has not been selected from among results of measurement of the overlap region R_{ij} in the result Fi of measurement performed by the laser radar device Mi (step S1402).

Next, the control device **101** determines whether or not there is an object detected by the laser radar device Mj at a coordinate position Li-k of the object obtained from the selected result Fi-k on the basis of the result Fj of measurement performed by the laser radar device Mj (step S1403). The coordinate position Li-k of the object is the coordinate position of the object calculated in step S1302 illustrated in FIG. **13**.

Here, if there is an object detected by the laser radar device Mj (YES in step S1403), the control device **101** determines that the object at the coordinate position Li-k as is an actually existing object (step S1404), and causes the process to proceed to step S1406. On the other hand, if there is no object detected by the laser radar device Mj (NO in step S1403), the control device **101** determines that the object at the coordinate position Li-k is an erroneously detected object (step S1405).

Next, whether or not there is a result indicating positional information regarding an object that has not been selected among the results of measurement of the overlap region R_{ij} in the result Fi of the measurement performed by the laser radar device Mi is determined (step S1406). Here, if there is a result that has not been selected (YES in step S1406), the control device **101** causes the process to return to step S1402.

On the other hand, if there is no result that has not been selected (NO in step S1406), the control device **101** determines whether or not there is an object in another region different from the overlap region R_{ij} on the basis of the result Fi of the measurement performed by the laser radar device Mi (step S1407).

Here, if there is an object in another region (YES in step S1407), the control device **101** determines that the object in the other region is an actually detected object (step S1408), and causes the process to return to the step in which the process for determining an actually existing object is initiated. On the other hand, if there is no object in another region (NO in step S1407), the control device **101** causes the process to return to the step in which the process for determining an actually existing object is initiated.

Thus, objects existing around the vehicle V may be detected while avoiding erroneous detection of an object in the overlap region R_{ij} between the adjacent laser radar devices Mi and Mj.

If a plurality of laser radar devices Mj adjacent to the laser radar device Mi are detected in step S1305, for example, the control device **101** executes the processing in steps S1306 and S1307 for each laser radar device Mj. In addition, when the process for determining an actually existing object has already been executed for a certain overlap region R_{ij}, the control device **101** may omit the process for determining an actually existing object for the certain overlap region R_{ij}.

As described above, according to the object detection apparatus **100** according to the embodiment, the scan ranges of the laser radar devices Mi and Mj may be scanned in opposite directions such that the timings at which the laser radar devices Mi and Mj scan the overlap region R_{ij} match. Therefore, the laser radar devices Mi and Mj may intentionally detect objects erroneously detected by receiving reflected light of laser light emitted from the adjacent laser radar devices in the overlap region R_{ij}.

In addition, according to the object detection apparatus **100**, it is possible to determine whether or not the coordinate position Fi of an object obtained from the result Fi of measurement of the overlap region R_{ij} performed by the laser radar device Mi and the coordinate position Fj of an object obtained from the result Fj of measurement of the overlap region R_{ij} performed by the laser radar device Mj match. According to the object detection apparatus **100**, if it is determined that the coordinate positions Fi and Fj of the objects match, an object existing in the overlap region R_{ij} may be detected. Therefore, among objects existing in the overlap region R_{ij} detected by the laser radar devices Mi and Mj, an object detected by both the laser radar devices Mi and Mj may be determined as an actually existing object, and objects other than the foregoing object may be determined as erroneously detected objects.

In addition, according to the object detection apparatus **100**, it is possible to detect an object existing in another region different from the overlap region R_{ij} on the basis of a result of measurement of the other region different from the overlap region R_{ij} performed by the laser radar device Mi. In addition, according to the object detection apparatus **100**, it is possible to detect an object existing in another region different from the overlap region R_{ij} on the basis of a result of measurement of the other region different from the overlap region R_{ij} performed by the laser radar device Mj.

In addition, according to the object detection apparatus **100**, it is possible to output the coordinate position of a detected object in the overlap region R_{ij} or the coordinate position of a detected object in another region different from the overlap region R_{ij}. Therefore, for example, objects existing around the vehicle V may be displayed on the display **320** or the like in three dimensions, thereby supporting operation and parking of the vehicle V.

Thus, according to the object detection apparatus **100**, erroneous detection of an object in the overlap region R_{ij} caused when the laser radar device Mi or Mj receives reflected light of laser light emitted from the other laser radar device may be avoided, which improves the accuracy of detecting an object existing around the vehicle V, a building, or the like.

The method for detecting an object described in the embodiment may be realized by executing a prepared program using a computer such as a personal computer or a work station. The object detection program is recorded on a computer-readable recording medium such as a hard disk, a flexible disk, a compact disc read-only memory (CD-ROM), a magneto-optical (MO) disk, or a digital versatile disc (DVD), and executed when read from the recording medium using a computer. The object detection program may be distributed through a network such as the Internet.

In addition, the object detection apparatus **100** described in the embodiment may be realized by an application-specific integrated circuit (ASIC) such as a standard cell or a structured ASIC or programmable logic device (PLD) such as a field-programmable gate array (FPGA).

All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although the embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. An object detection apparatus, comprising:

a first radar configured to measure first positional information regarding a first object existing in a first scan range on the basis of first reflected wave of first wave radiated onto the first scan range including a first region;

a second radar configured to measure second positional information regarding a second object existing in a second scan range on the basis of second reflected wave of second wave radiated onto the second scan range including the first region and a second region, which is located outside the first scan range, the second wave being radiated in such a way as to scan the first region in a direction opposite a direction in which the first radar radiates the first wave at a timing at which the first radar scans the first region; and

a processor configured to:

determine, when a first position relating to the first positional information and a second position relating to the second positional information are included in the first region, whether the first position and the second position match, and

detect a third object existing in the first scan region when the first position and the second position match.

2. The object detection apparatus according to claim **1**,

wherein the first scan range includes a third region, which is located outside the first region, and

wherein the processor detects fourth object existing in the second region or the third region on the basis of a result of measurement of the third region performed by the first radar or a result of measurement of the second region performed by the second radar.

3. The object detection apparatus according to claim **2**,

wherein the processor outputs a position of the third object existing in the first region or another position of the fourth object existing in the second region or the third region.

4. The object detection apparatus according to claim **1**,

wherein the processor calculates the first position on the basis of a first mounted position of the first radar and a result of measurement of the first region performed by the first radar, and

wherein the processor calculates the second position on the basis of a second mounted position of the second radar and a result of measurement of the first region performed by the second radar.

5. A method for detecting an object executed by a computer, the method comprising:

obtaining a first result of measurement from a first radar that measures first positional information regarding a first object existing in a first scan range on the basis of first reflected wave of first wave radiated onto the first scan range;

obtaining a second result of measurement from a second radar that measures second positional information regarding a second object existing in a second scan range on the basis of second reflected wave of second wave radiated onto the second scan range including a first region, which is located inside in the first scan range, and a second region, which is located outside the first scan range, the second wave being radiated in such a way as to scan the first region in a direction opposite a direction in which the first radar radiates the first wave at a timing at which the first radar scans the first region;

determining, when a first position relating to the first positional information and a second position relating to the second positional information are included in the first region, whether the first position and the second position match; and

detecting a third object existing in the first scan region when the first position and the second position match.

6. The method according to claim **5**,

wherein the first scan range includes a third region, which is located outside the first region, and

the method further comprising:

detecting fourth object existing in the second region or the third region on the basis of a result of measurement of the third region performed by the first radar or a result of measurement of the second region performed by the second radar.

7. The method according to claim **6**, further comprising:

outputting a position of the third object existing in the first region or another position of the fourth object existing in the second region or the third region.

8. The method according to claim **5**,

wherein the determining calculates the first position on the basis of a first mounted position of the first radar and a result of measurement of the first region performed by the first radar, and calculates the second position on the basis of a second mounted position of the second radar and a result of measurement of the first region performed by the second radar.

9. The A computer-readable recording medium storing a program for causing a computer to execute a procedure for detecting an object, the procedure comprising:

obtaining a first result of measurement from a first radar that measures first positional information regarding a first object existing in a first scan range on the basis of first reflected wave of first wave radiated onto the first scan range;

obtaining a second result of measurement from a second radar that measures second positional information regarding a second object existing in a second scan range on the basis of second reflected wave of second wave radiated onto the second scan range including a first region, which is located inside in the first scan range, and a second region, which is located outside the first scan range, the second wave being radiated in such a way as to scan the first region in a direction opposite a direction in which the first radar radiates the first wave at a timing at which the first radar scans the first region;

determining, when a first position relating to the first positional information and a second position relating to the second positional information are included in the first region, whether the first position and the second position match; and

detecting a third object existing in the first scan region when the first position and the second position match.

10. The computer-readable recording medium according to claim **9**,

wherein the first scan range includes a third region, which is located outside the first region, and

the method further comprising:

detecting a fourth object existing in the second region or the third region on the basis of a result of measurement of the third region performed by the first radar or a result of measurement of the second region performed by the second radar.

11. The computer-readable recording medium according to claim **10**, the procedure further comprising:

outputting a position of the third object existing in the first region or another position of the fourth object existing in the second region or the third region.

12. The computer-readable recording medium according to claim **9**,

wherein the determining calculates the first position on the basis of a first mounted position of the first radar and a result of measurement of the first region performed by the first radar, and calculates the second position on the basis of a second mounted position of the second radar and a result of measurement of the first region performed by the second radar.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,046,599 B2
APPLICATION NO. : 13/945212
DATED : June 2, 2015
INVENTOR(S) : Takeshi Morikawa et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the claims

Claim 9, Column 20, Line 38:

Delete "The A" and insert --A--, therefor.

Signed and Sealed this
Thirteenth Day of October, 2015

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office